Cosmology with Radio Surveys

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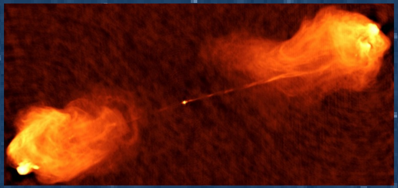
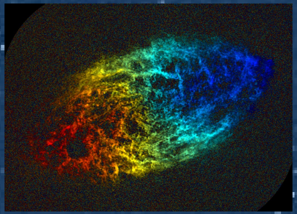




Rencontres du Vietnam, 2 August 2013

Outline

Radio Telescopes (incl SKA split site details)
Radio emission mechanisms: continuum sources vs HI sources
Questions in cosmology + Probes in the radio

Results:

1. Forecasting cosmological constraints using future HI surveys
2. Forecasting cosmological constraints using future radio continuum surveys
3. Clustering and bias of radio continuum sources in FIRST survey
4. Clustering and bias of HI sources in ALFALFA
5. Exploring probes of GR using HI data

Reflections

Radio Telescopes

Single Dish:

GBT
Arecibo
Effelsberg
Parkes

Interferometers:

JVLA
GMRT
WSRT
eMerlin
ASKAP
MeerKAT

LOFAR

PAPER
MWA

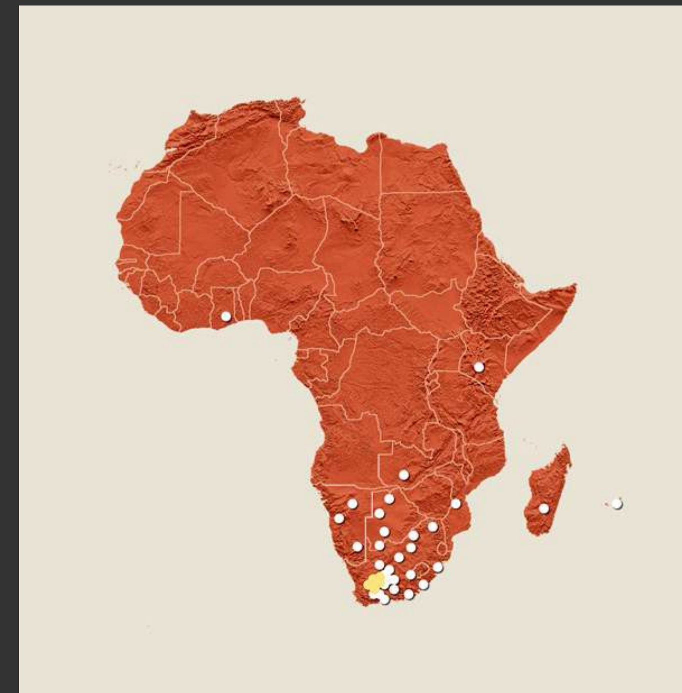
SKA

Square Kilometer Array (2018 & beyond)

Spilt between South Africa & Australia

4 telescopes: Dish_SA, Dish_A, Low_AA, Dense_AA

Some of the antenna concepts under investigation for the SKA. Above: high frequency dishes. Above right: mid frequency aperture array tiles. Below right: low frequency aperture array dipoles.



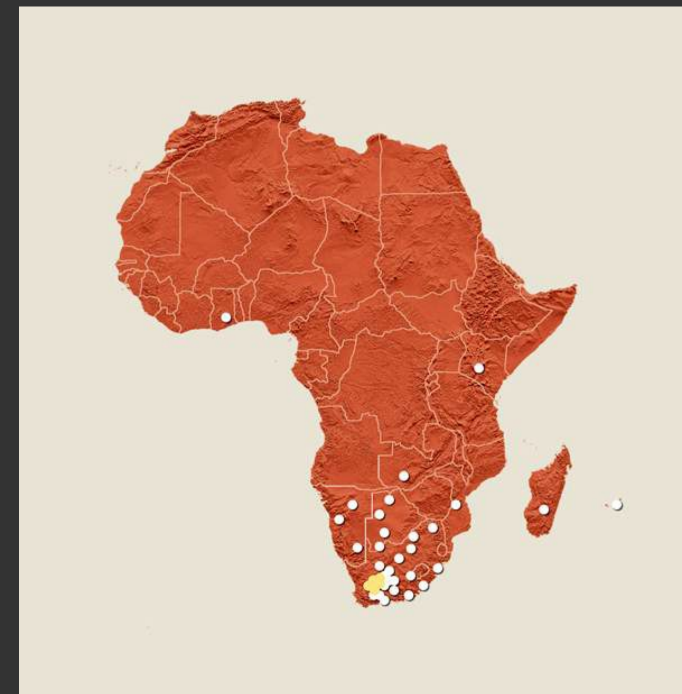
Currently in SA: KAT 7

Next: MeerKAT (64 dishes)

Square Kilometer Array (2018 & beyond)

Spilt between South Africa & Australia

4 telescopes: Dish_SA, Dish_A, Low_AA, Dense_AA



Currently in SA: KAT 7 + people

Next: MeerKAT (64 dishes)

The SKA will be constructed in two phases:

Phase one

- 190 SKA dishes and 64 MeerKAT dishes equipped with single pixel feeds will be located in South Africa (SKA1 dish mid).
- 60 SKA dishes and 36 ASKAP dishes equipped with phased array feeds will be located in Australia (SKA1 dish survey).
- 50 stations of low frequency aperture array antennas, with about 10 000 antennas per station, will be located in Australia (SKA1 AA low).

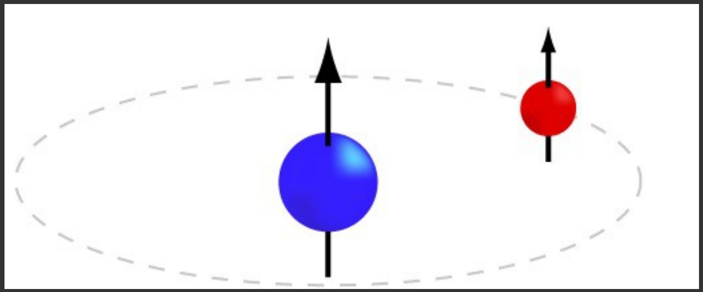
Phase two

- The dish array will be extended to about 3 000 dishes with a maximum separation of 3 000 km across Southern Africa (SKA2 dish mid).
- The low frequency aperture arrays will be extended to 250 stations in Australia (SKA2 AA low).
- A new component comprising 250 mid frequency aperture array stations will be located in South Africa (SKA2 AA mid).

Radio emission mechanisms

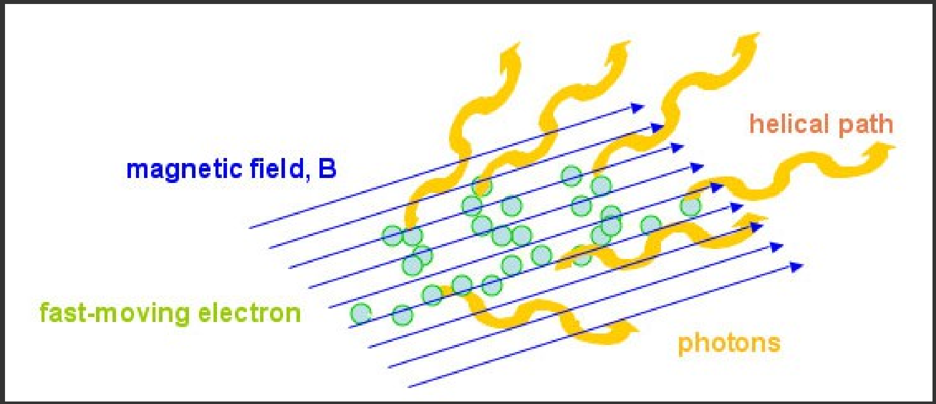
Line emission/absorption:

HI (21cm hyperfine transition)
Molecular lines eg CO
Masers
Radio recombination lines

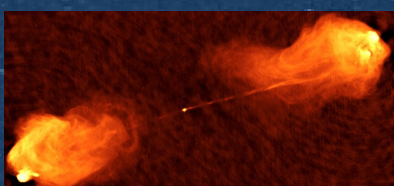


Continuum emission:

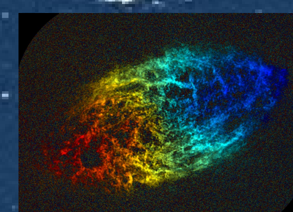
Synchrotron
Free-free
Inverse Compton
Blackbody



Radio galaxy:
* synchrotron emission from jets of charged particles
  associated with black hole AGN at centre
* see easily at high redshift=> **huge volumes** but no z



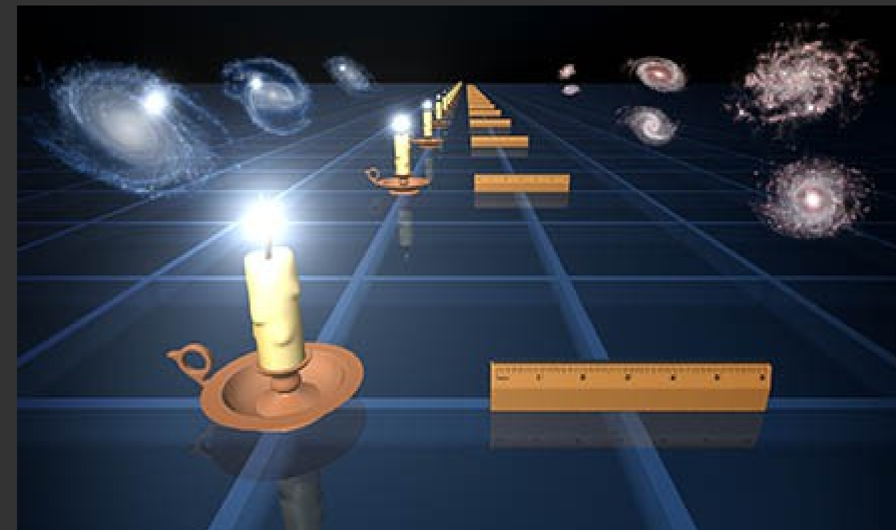
Starforming galaxy:
* radio continuum from
synchrotron and free-free
* fainter than AGN



HI (neutral hydrogen)
Line so redshift and velocities in galaxies
Faint so low-z

Questions in Cosmology

Dark matter/energy: What, How much? Or is GR wrong?
Initial conditions?

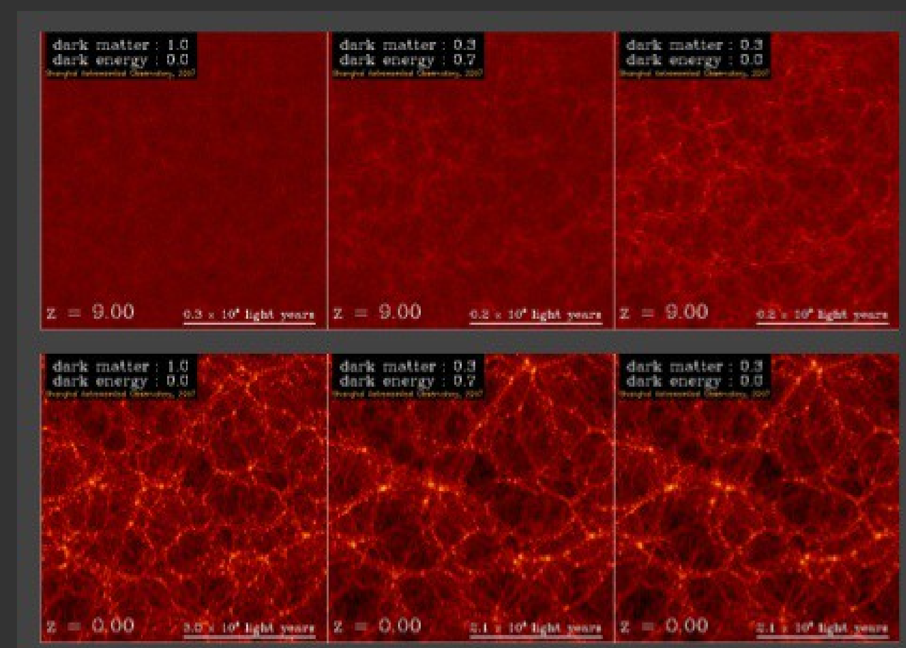


Probe by:

* Background expansion measures
  (eg lum distance, angular diam dist:
  standard candles and rulers)

* Evolution of density fluctuations

* Exotic effects of GR modification



SKA focus 2004:
BAO (standard ruler) using HI survey
Weak Lensing – shear

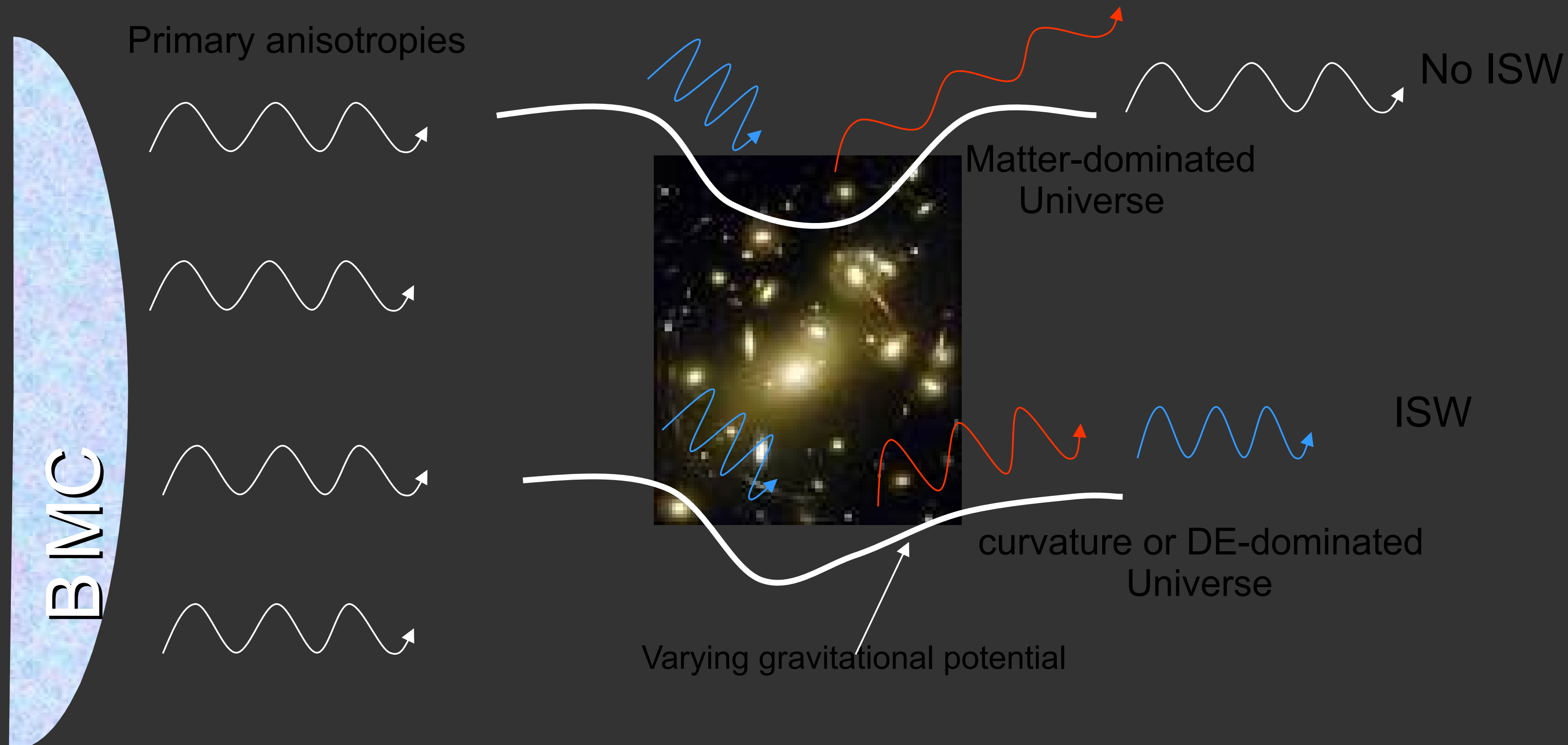
1. Cosmology with future HI radio surveys

With SKA, redshift survey to z>1, half sky .. fantastic! But when?

BAO
clustering evolution
redshift space distortions
etc ..

1. Cosmology with future HI surveys: ISW example

Integrated Sachs Wolfe anisotropies



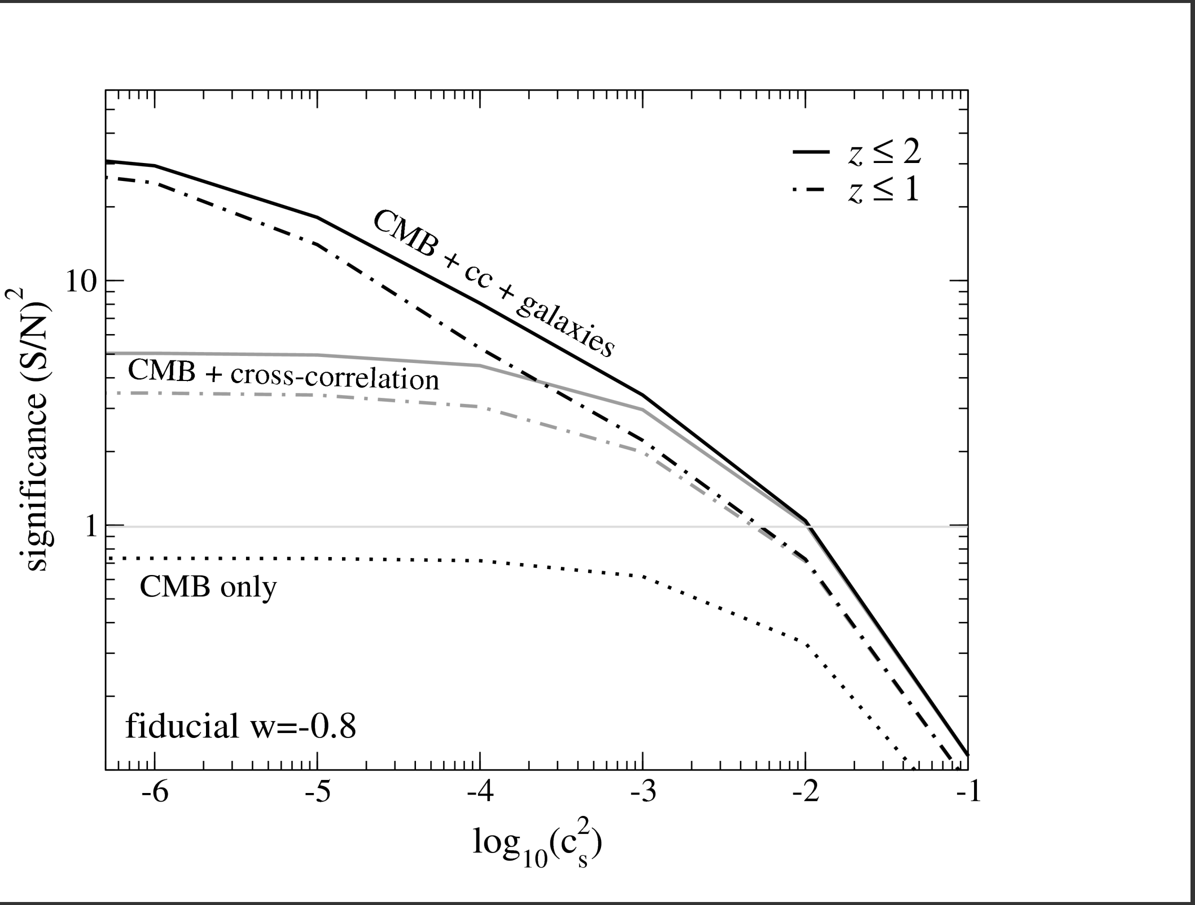
Induces a secondary layer of large-scale anisotropies

1. Cosmology with future HI surveys: ISW example

Dark Energy from dynamical scalar field?

* quintessence: sound speed constant: c_s=1
* other models like k-essence (with non-standard kinetic term): c_s!=1

Constraints on DE sound speeds possible for low speeds using ISW “tomography”



Torres-Rodriguez & Cress MNRAS 2008

2. Cosmology with Future Radio Continuum Surveys (no redshifts)

(as in Raccanelli.. CC… et al)

Surveys: EMU on ASKAP + WODAN on WRST (full sky, 3×10^7 sources)

1. Power spectrum (angular)

2. Lensing magnification

3. ISW (CMB x radio)

Testing gravity:

Changes to background expansion
fluctuation growth funciton of η,μ

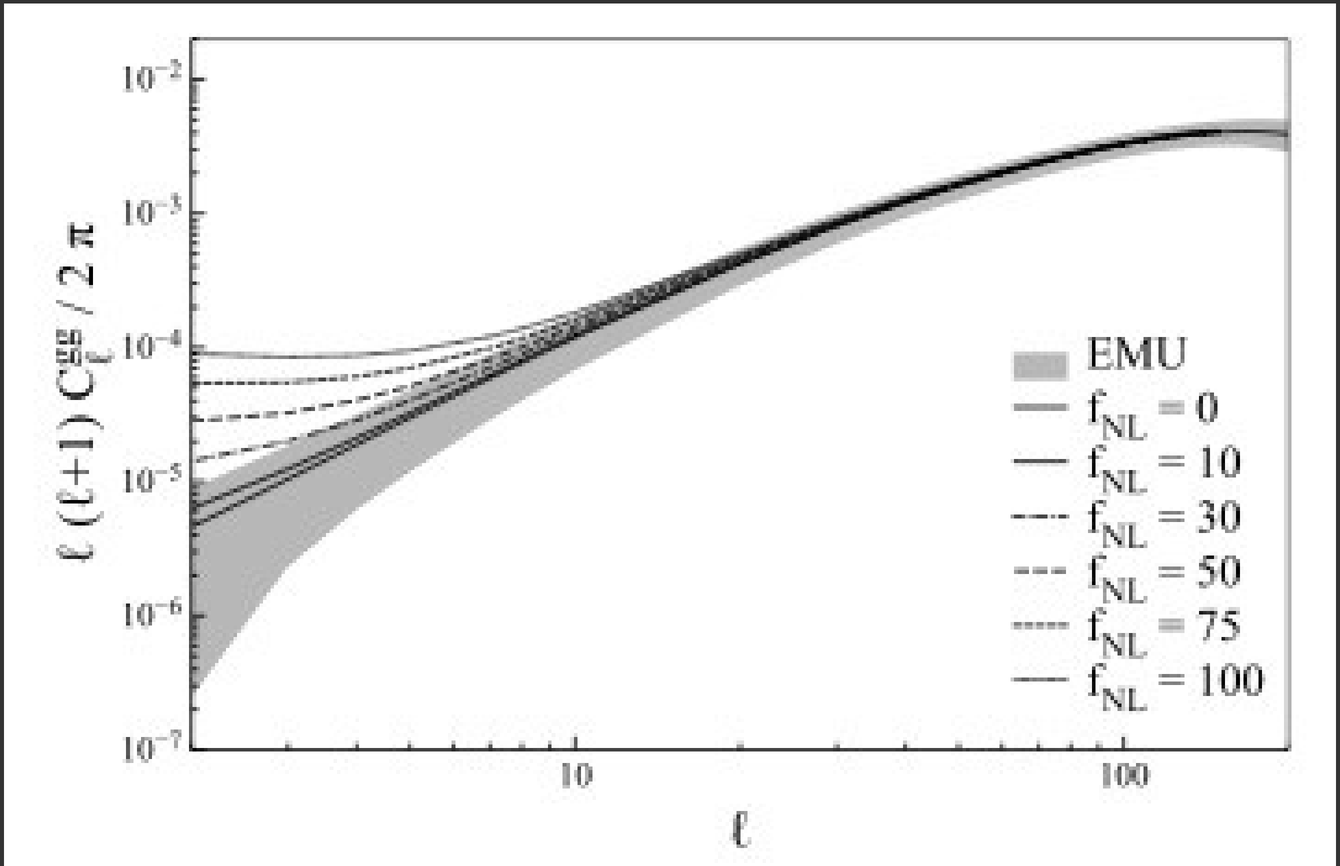
$$ds^2 = -a^2(\tau)[(1+2\Psi)d\tau^2 - (1-2\Phi)d\vec{x}^2],$$

$$\frac{\Phi}{\Psi} = \eta(a,k),$$

$$k^2\Psi = -4\pi G a^2 \mu(a,k)\rho\Delta,$$

2. Cosmology with Future Radio Continuum Surveys
(as in Raccanelli.. CC… et al)

Angular power spectrum



Probe non-gaussian initial conditions?

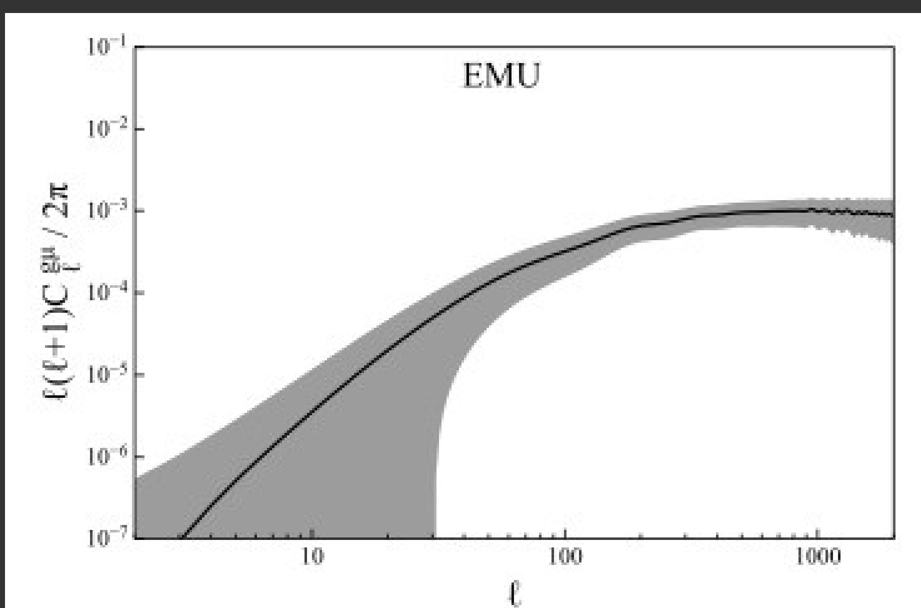
2. Cosmology with Future Radio Continuum Surveys
(as in Raccanelli.. CC… et al)

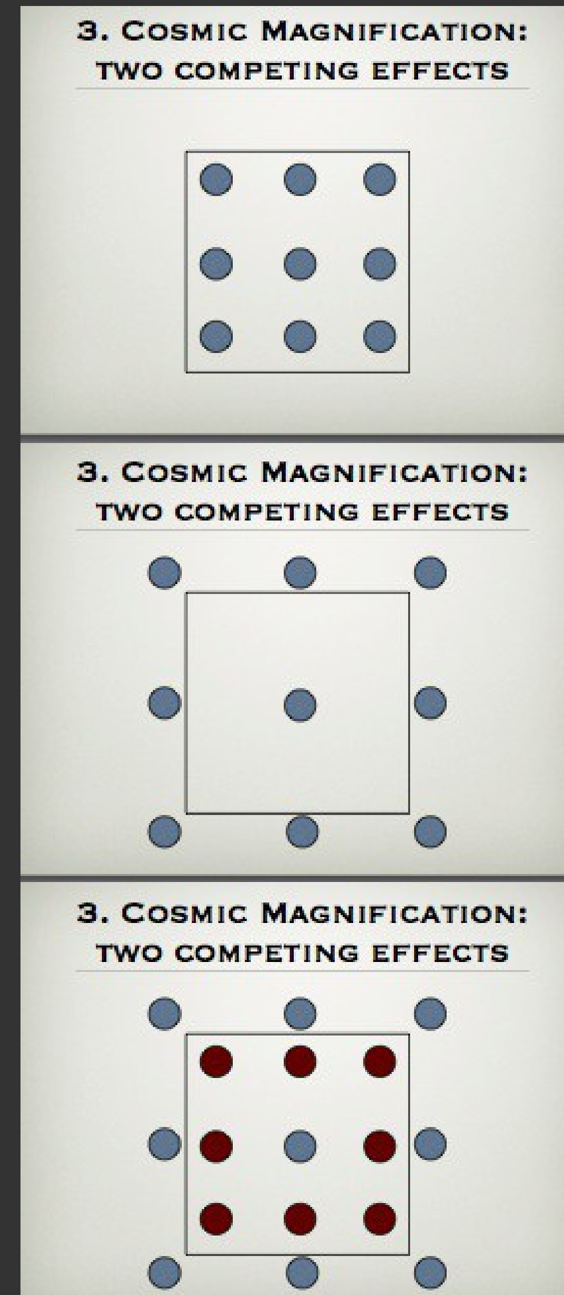
Lensing Magnification

Cross correlate z>1 radio sources
with lower-z tracers of structure
(eg EMUxDES, Panstarrs)

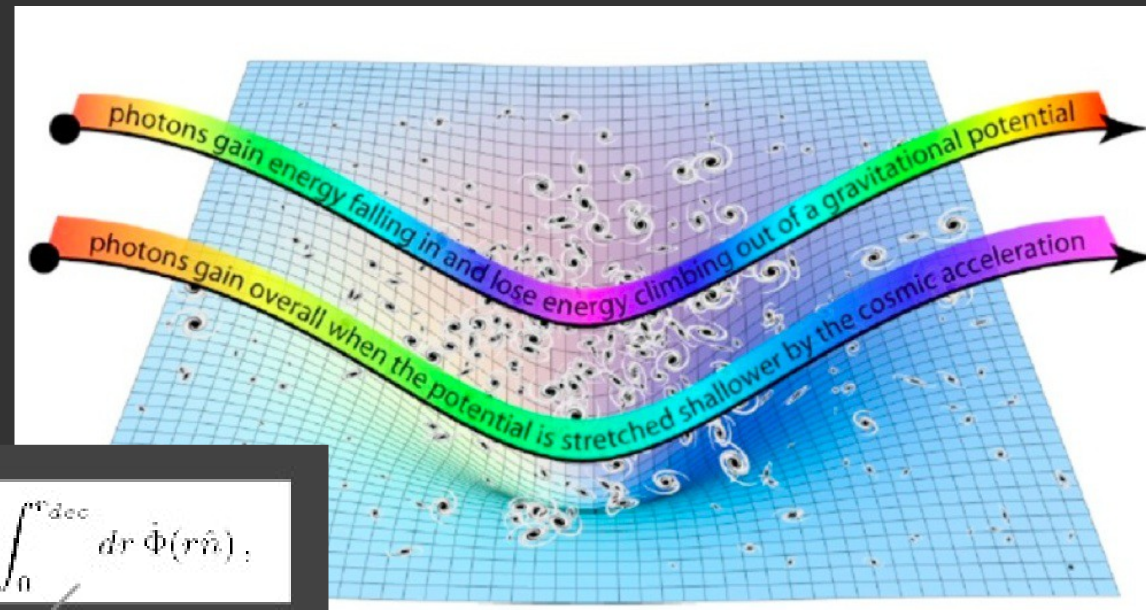
Must be able to identify
all low-z radio sources

Sensitive to high-z flux distribution





2. Cosmology with Future Radio Continuum Surveys
(as in Raccanelli.. CC… et al)



ISW:

CMB temp x number radio gals

$$\frac{\delta N}{N_0}(\hat{n}) = \int_0^z b_{HI}(z)\,\frac{d\bar{N}}{dz}\,\delta_m(z,\hat{n})\,dz\,.$$

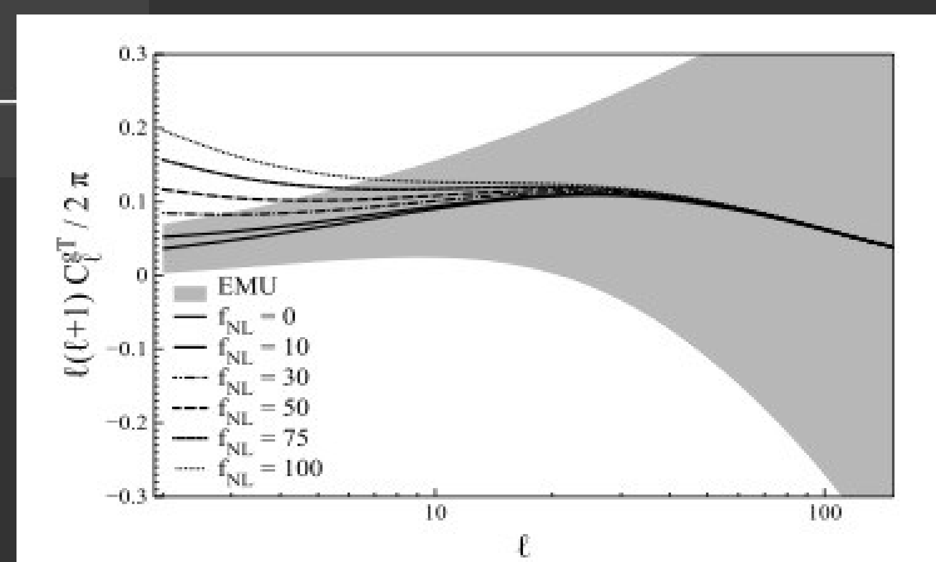
galaxies anisotropies

$$\frac{\delta T}{T_0}(\hat{n}) = -2\int_0^{r_{dec}} dr\,\dot{\Phi}(r\hat{n})\,,$$

ISW anisotropies

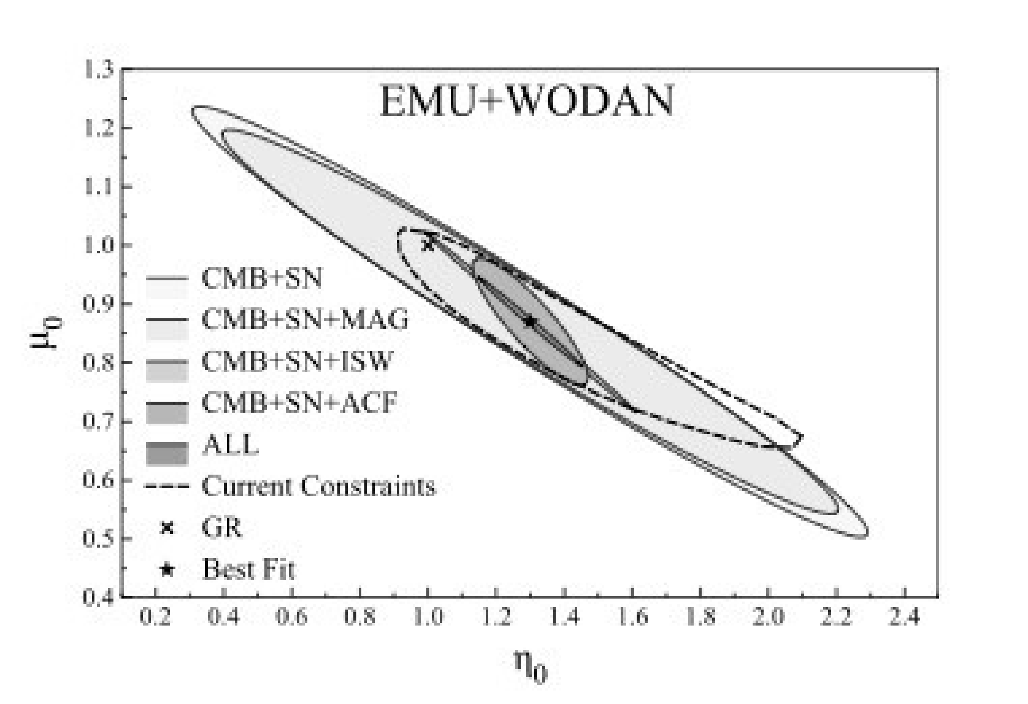
ISW-galaxies cross-correlation

$$C_\ell^{gT} = 4\pi \int \frac{dk}{k}\left\langle \frac{\delta N}{N_0}(k)\frac{\delta T}{T_0}(k')\right\rangle j_\ell^2(kr)$$

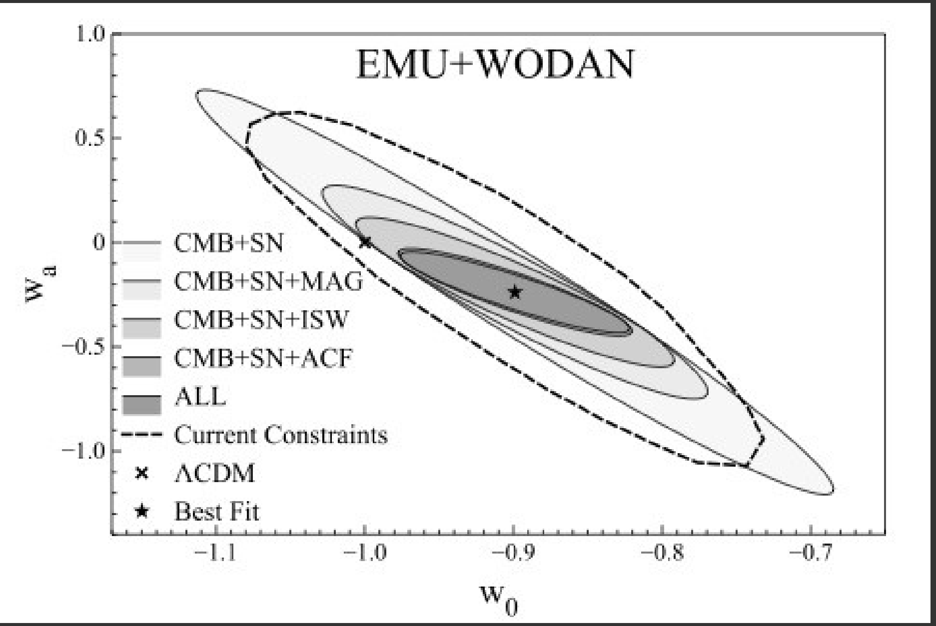


2. Cosmology with Future Radio Continuum Surveys
(as in Raccanelli.. CC… et al)

Constraints on modified gravity parameters:



w(z) constraints:



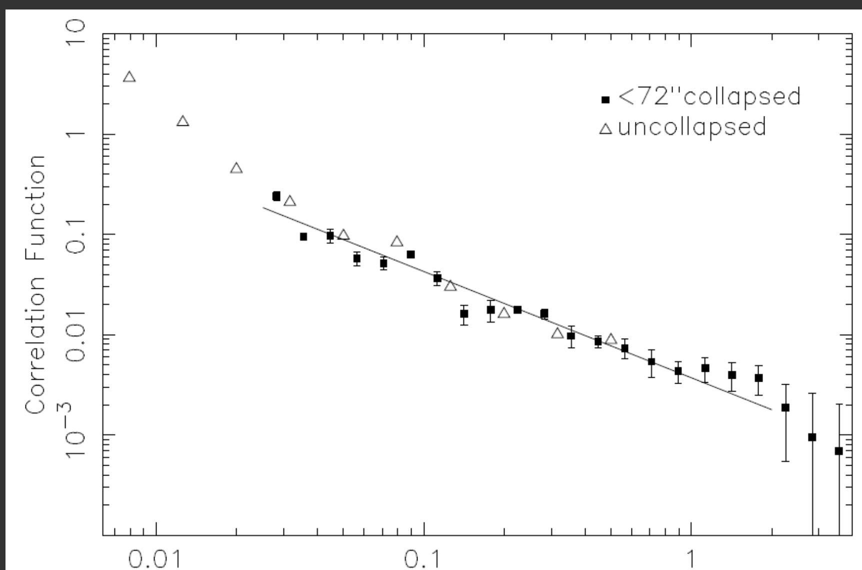
Cosmology with Radio Continuum Surveys…

What can be done with real data available now?

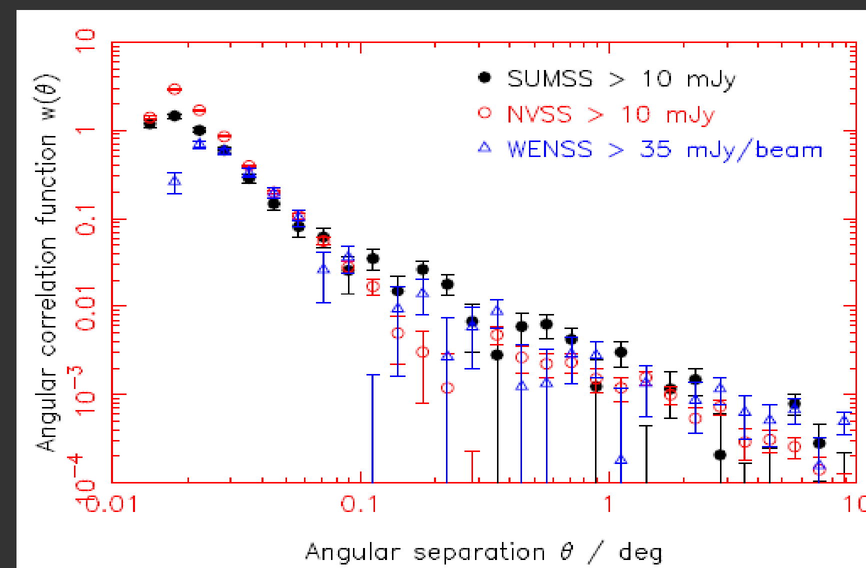
3. Measuring the bias of radio galaxies in FIRST using matching to SDSS

History of radio continuum clustering measurements

Webster (76), Peacock & Nicholson (91)
Cress (96) – first high significance measurement of angular clustering of radio sources
Magliocchetti (98), Overzier(03), Blake & Wall(02) – repeats/disputes/other radio surveys
Blake et al (04) – agreement: beware sidelobes!



Cress et al (96)



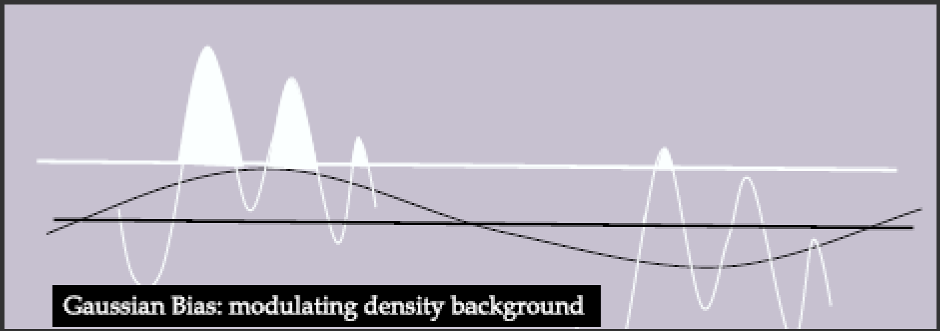
Blake et al (04)

Spatial correlation function inferences, bias indications

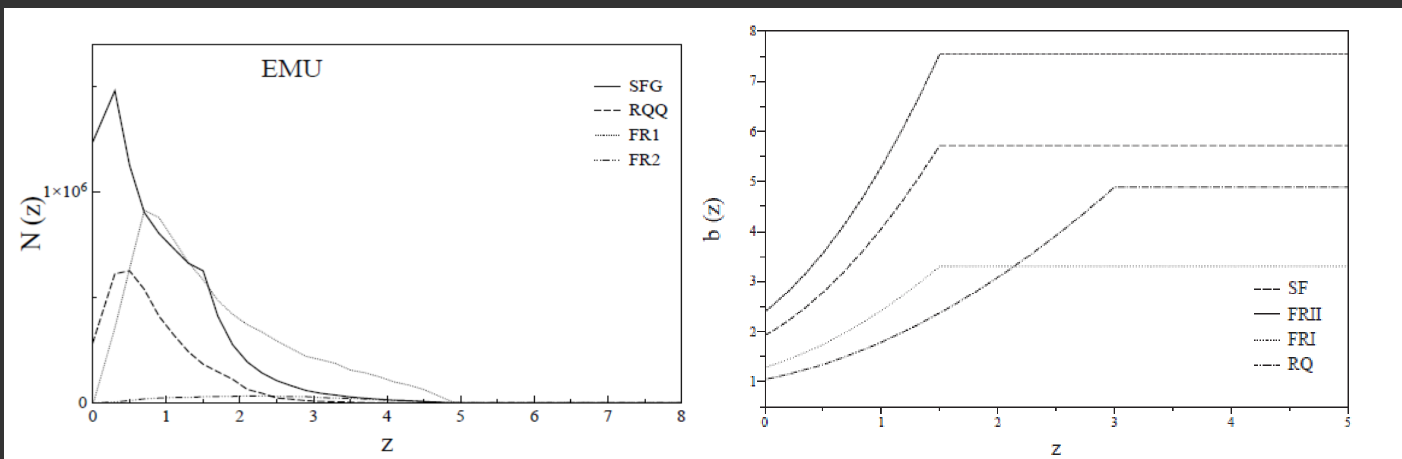
What is bias?

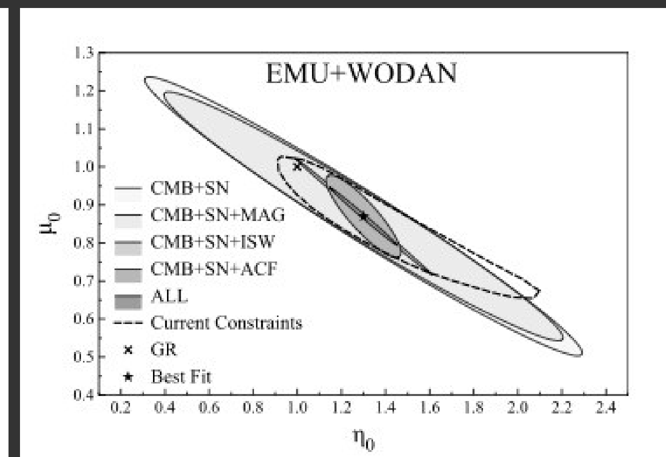
Relationship between dark matter and luminous matter

$$\xi(r, z) = b^2(M_{\mathrm{eff}}, z)\xi_{\mathrm{DM}}(r, z)$$



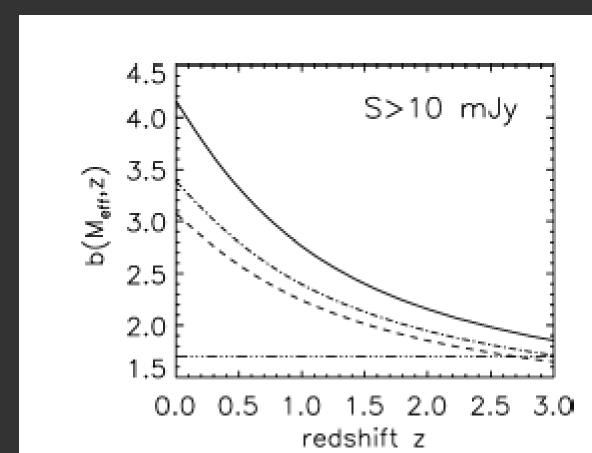
The role of bias in cosmology projects using radio continuum sources



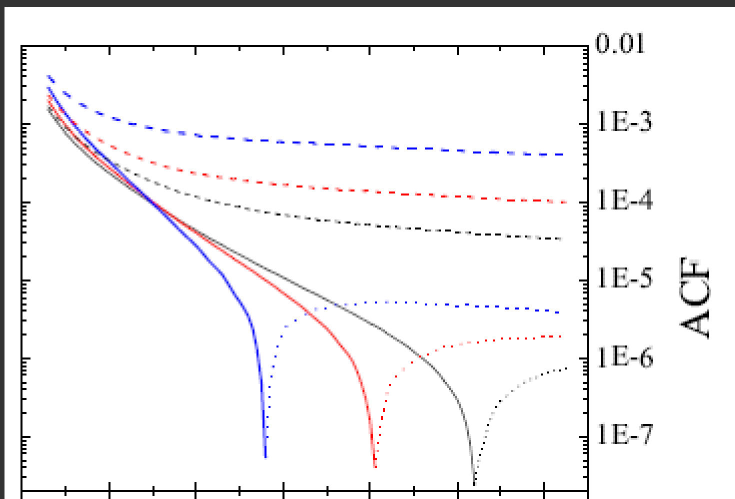


Bias assumptions in tests of modified gravity, non-gaussianity (Raccannelli et al 2011, Xia et al, etc.)

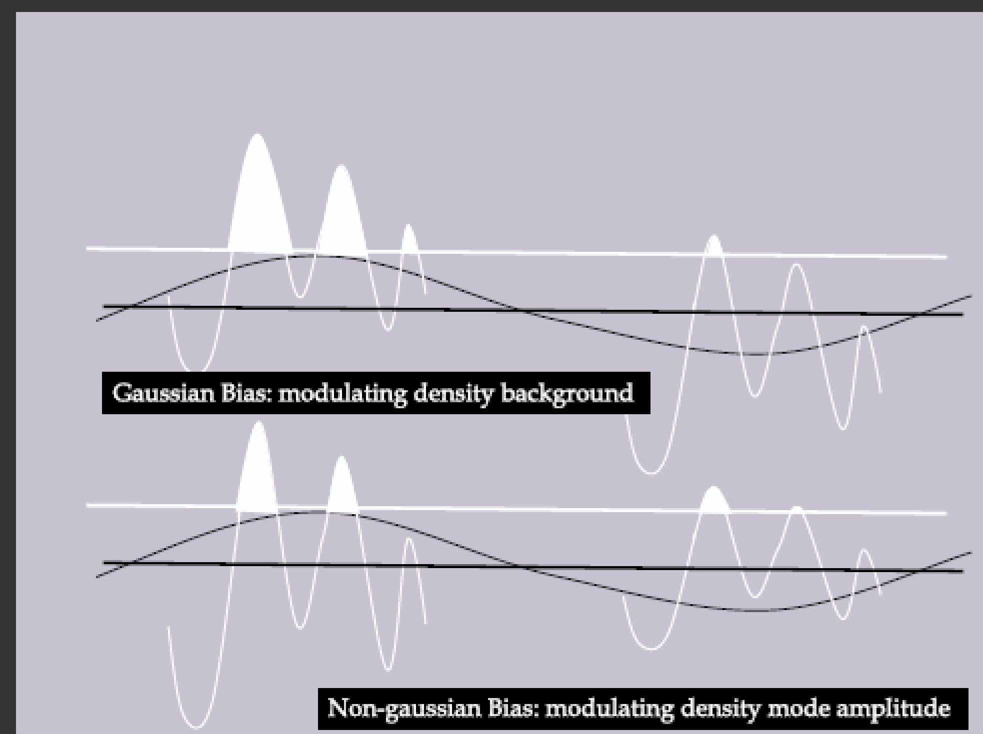
Bias unknown: compare Raccanelli et al 2008 (use NVSS/WMAP correlation & ISW to check Λ)



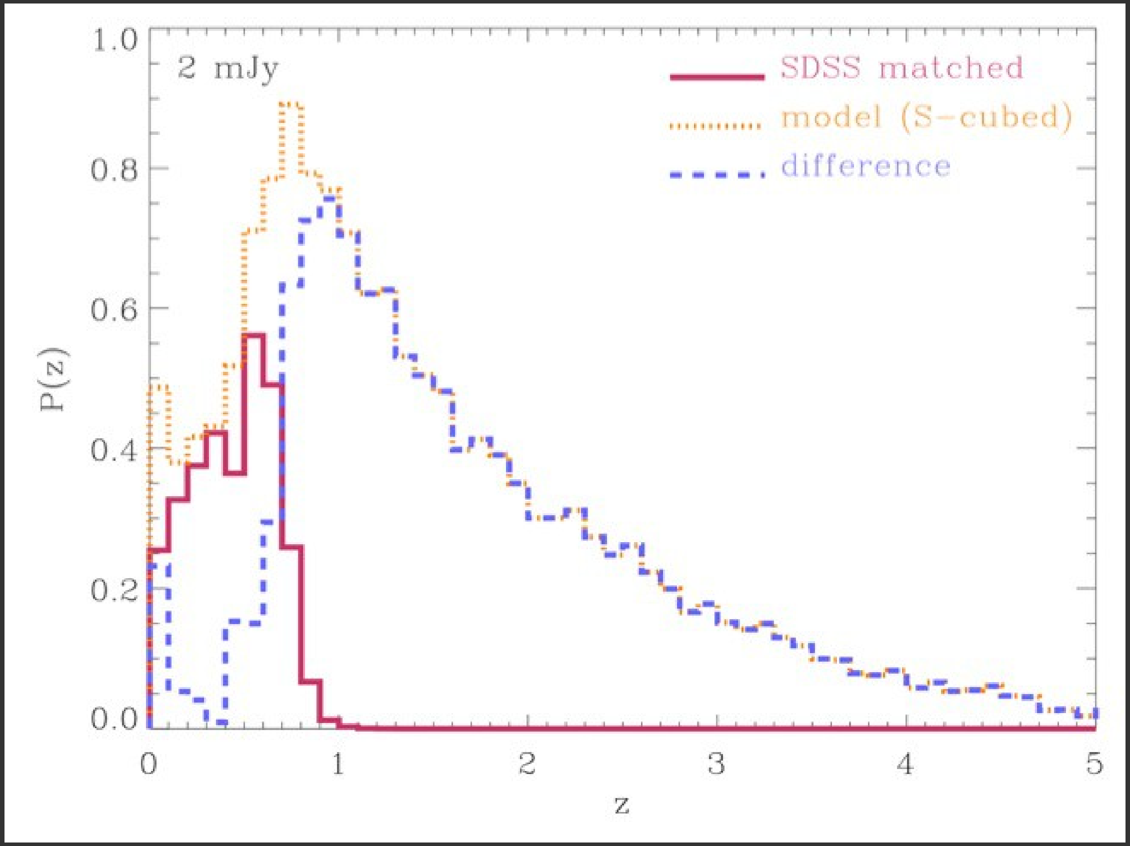
The role of bias in cosmology projects using radio continuum sources



Bias assumptions in tests of non-gaussianity
(Xia et al, etc.)



3. Probe bias at high-z using FIRST and SDSS combination



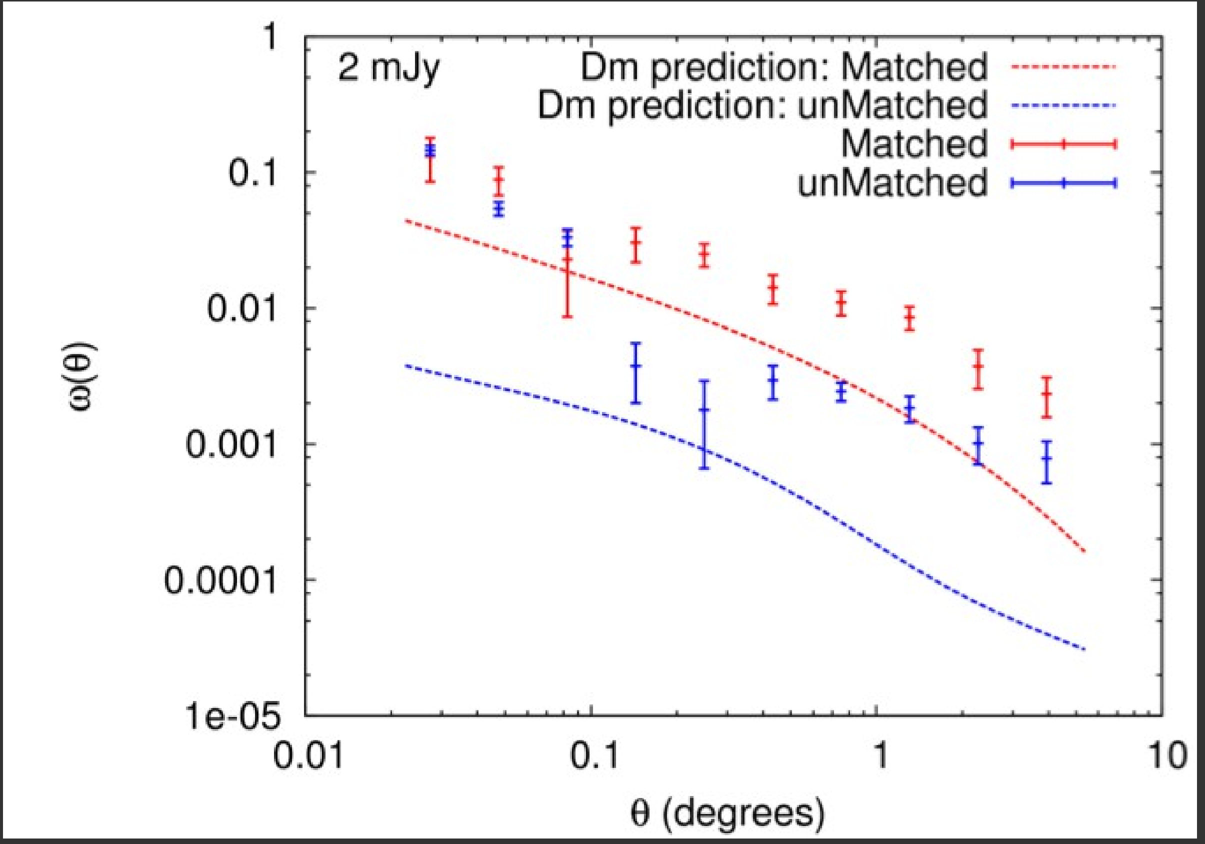
* Know average z-distribution of all FIRST sources from small-field obs & S^3 model
* Remove SDSS-matched sources from FIRST catalog (with photo-z's)
* Measure Clustering of Unmatched sources

  dN/dz_unmatched=dN/dz_all - dN/dz_matched

What do we measure for bias?

At θ = 0.4°, z_av ~ 0.7:

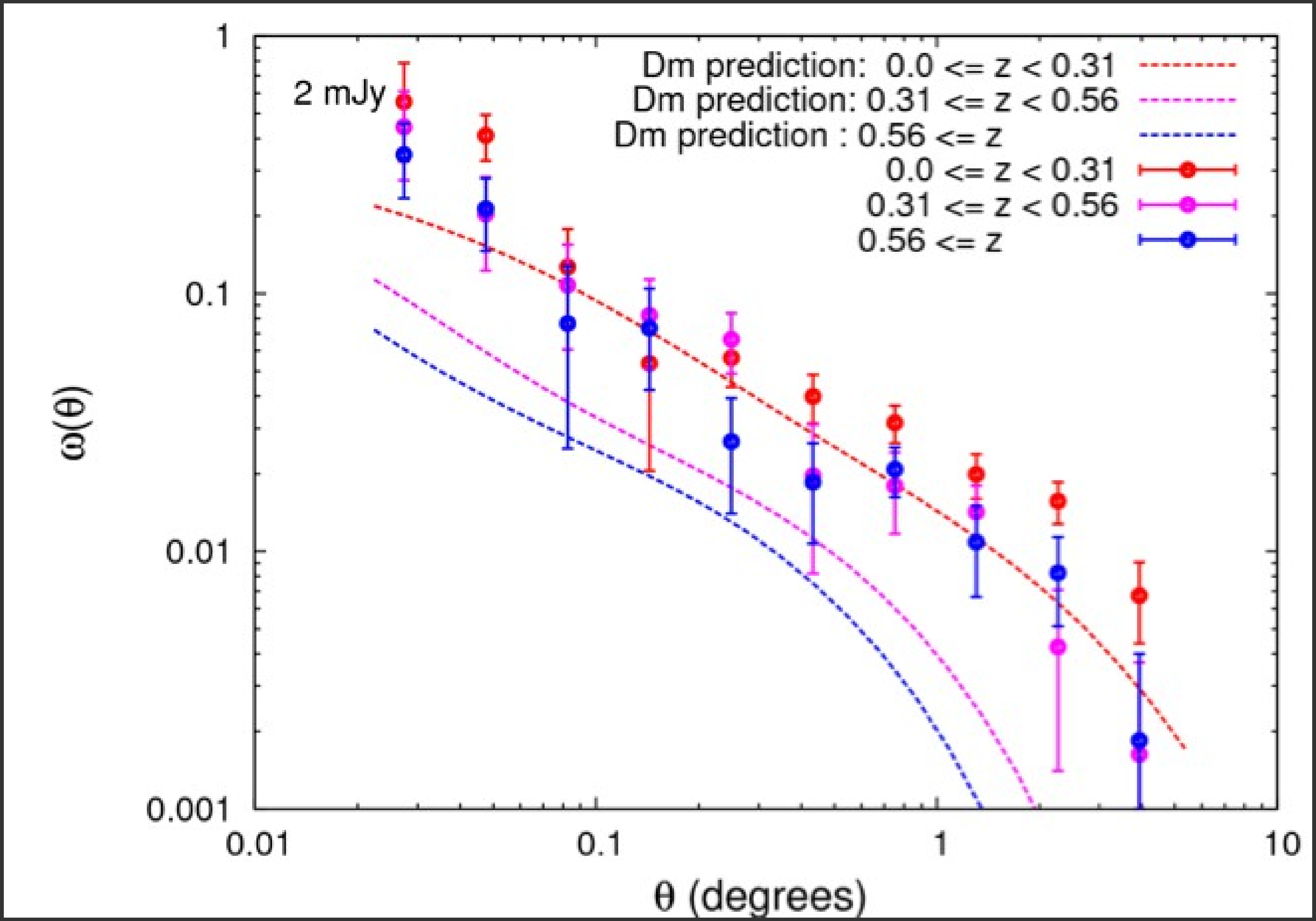
b = 3.0 ± 0.3



Passmoor et al 2012

Other probes of bias

Bias of optically matched galaxies in 3 slices



Move from clustering of radio continuum sources to …

clustering of HI galaxies …

…**still with real data**

4. Clustering in current HI surveys

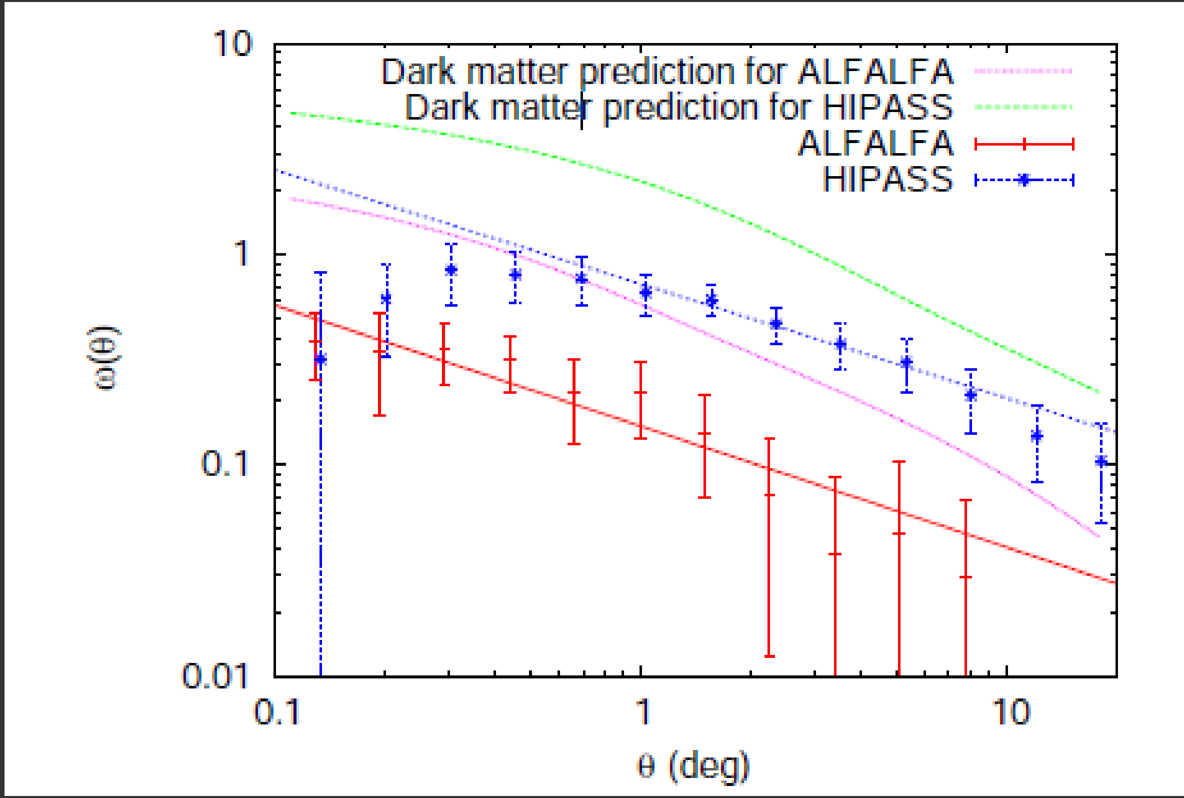
as in Passmoor, CC et al (2011)

HIPASS Survey

- Area = 20 000 deg²
- Depth z ≈ 0.02
- Has 4315 HI sources

ALFALFA Survey

- Area ≈ 400 deg²
- Depth z ≈ 0.06
- Has 1796 HI sources



HI-selected galaxies antibiased wrt to DM !
Less massive galaxies more antibiased?
NB for cosmological predictions for SKA (and galaxy evolution)

5. Using galaxies detected in HI to test gravity?

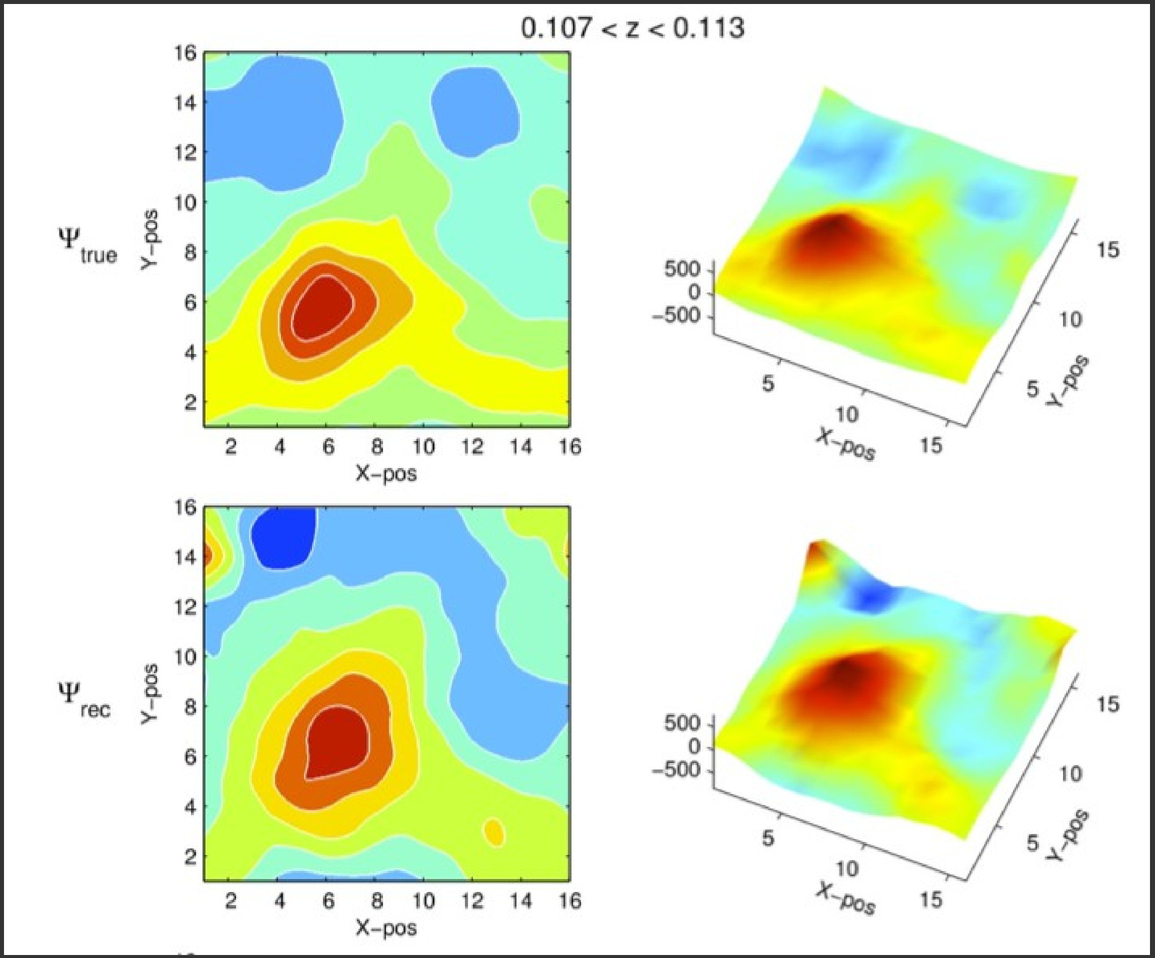
Johnston .. CC et al.

To test gravity: compare gravitational potential causing peculiar velocities of galaxies with gravitational potential seen by light (through eg lensing observations)

Potentials from peculiar velocity info using eg Tully-Fisher relation

Bayesian priors:
Use galaxy density and and expected power spectrum

Could reconstruct potetials z<0.3



Summary

Radio Telescopes (incl SKAsplitsite details)
Radio emission mechanisms: continuum surveys vs HI surveys
Questions in cosmology + Probes in the radio

Results:

1. Forecasting cosmological constraints using an HI survey – ISW tomography
   => potential to detect non-zero sound speed of dark energy

2. Forecasting cosmological constraints using future radio continuum surveys
   clustering: power spectrum ISW, lensing magnification
   => interesting constraints on modified gravity

3. Clustering and bias of radio continuum sources in FIRST survey
   Real data much harder than theory!
   Interesting constraint on bias of radio galaxies at z~0.7

4. Clustering and bias of HI sources in ALFALFA
   HI-selected galaxies anti-biased wrt DM (NB for SKA predictions)

5. Exploring probes of GR using HI data
   potential to reconstruct potential from TF estimates of peculiar velocities

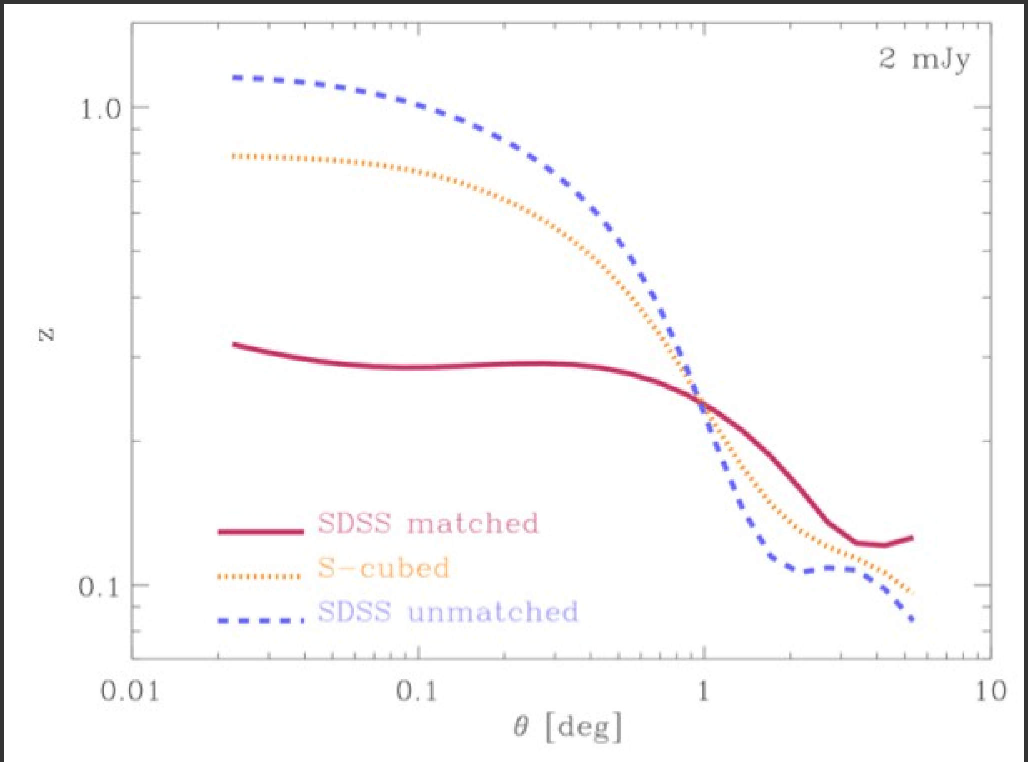
Reflections

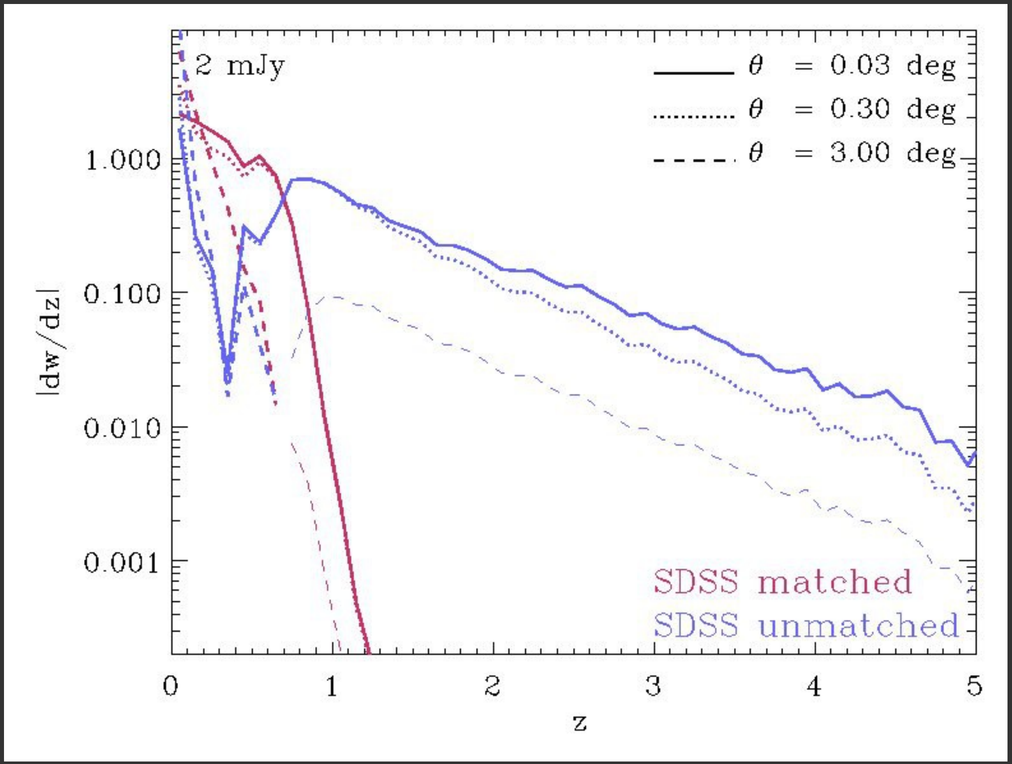
Considered:
clustering, ISW, some lensing, peculiar velocities

Not considered:

Redshift space distortions
Dark ages (before stars & quasars but potentially HI signatures)
Reionisation (HI signatures tracing early structures)
Pulsars as probe of gravity waves, GR
Lensing – shear near clusters, power spectrum – eMerlin proposal, heroic efforts on FIRST
Intensity mapping
Fine structure constant variations?
Radio detection of supernovae, gamma ray bursts
Polarisation?

What angles probe what z?





* although dN/dz peaks above z~1 for unmatched sample, w probes lower z

* at small angle: sidelobe/multicomponent questions

* at large angle: physical scales large at high-z where no clustering power

SKA

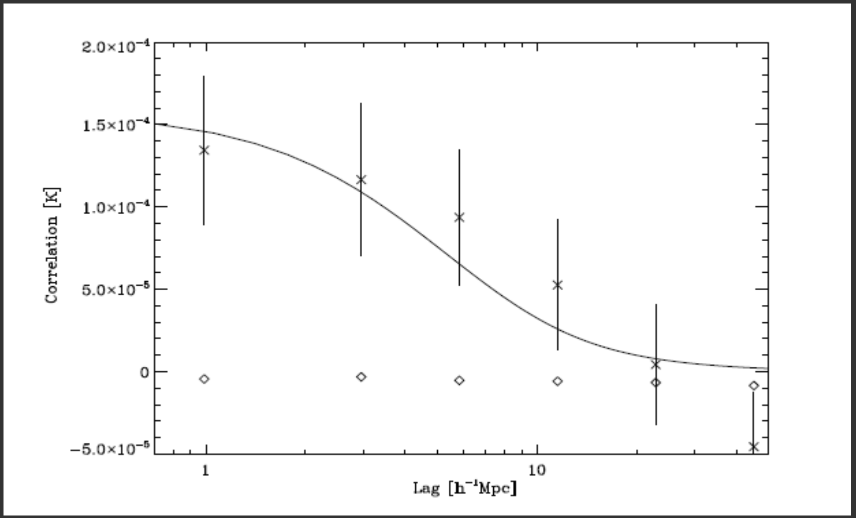
Assumed description for SKA1 and SKA2

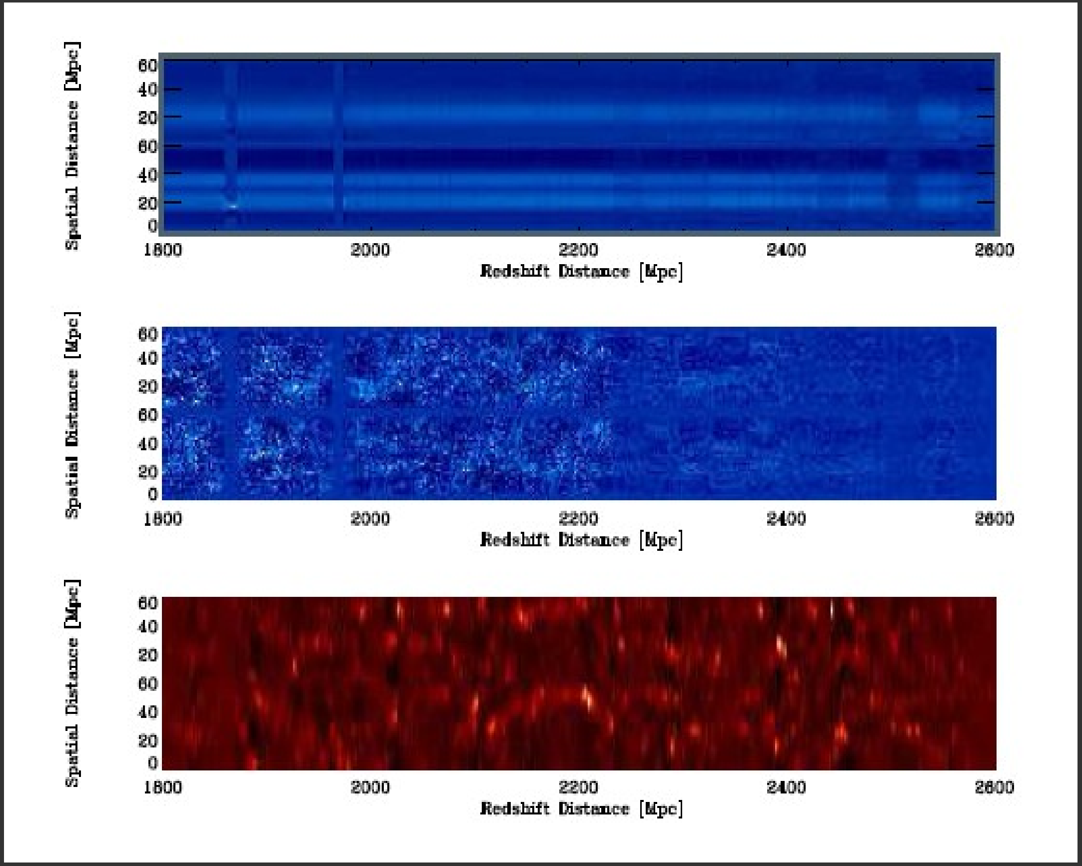
		SKA1_low	SKA1_mid	SKA2_low	SKA2_mid_dish	SKA2_AIP_AA	AIP_PAF	Comments
Collector type		Sparse AA [1]	15m dish [1]	Sparse AA [1]	15m dish [1]	Dense AA [1]	15m dish+PAF [1]	Offset feed dishes
No. of collectors		280 [3][9]	250 [1]	280 [3][10]	2,500 [11]	280 [3]	2000 [15]	
Frequency range	GHz	0.07 – 0.45 [1]	0.45 – 3.0 [1]	0.07 – 0.45 [2]	0.45 – 10 [11]	0.4 – 1.4 [2]	0.45 – 3.0 [13]	50MHz goal
Max bandwidth	GHz	0.38 [1]	1.5 [8]	0.38 [2]	*Depends on feed*	1.0 [8]	0.3	
Dish feeds: 1.	GHz		0.45 – 0.9 [1]				0.45 – 0.9 [13]	
2.	GHz		0.8 – 1.6 [1]		To be decided		0.8 – 1.6 [13]	
3.	GHz		1.5 – 3.0 [1]				1.5 – 3.0 [13]	
Effective FoV	deg^2		*1GHz:* 1.0 [1]	200 [4]	*1GHz:* 1.0 [1]		*0.5GHz:* 144 deg^2 [13] *1GHz:* 36 deg^2 [13] *2GHz:* 9 deg^2 [13]	15m dish FoV
No. of beams		160 [1]	1		1		36	
Sensitivity: /element	m^2K^{-1}	*131 MHz:* 7.2 [8]	*1-2GHz:* 4.0 [8]	*>90MHz:* 14.3 [8]	4.0 [8]	*<1.2GHz:* 36 [8]	*1-2GHz:* 3.5 [14]	
total sensitivity	m^2K^{-1}	*131MHz:* 1,515 [1] *300 MHz:* 889 [1]	*1-2GHz:* 1,031 [1] *0.45-1GHz:* 773 [1]	*>90MHz:* 4,000 [2]	10,000 [2]	*<1.2GHz:* 10,000 [2] *1.4GHz:* 5,000 [2]		Sensitivity of AA on boresight

Other Simulations:

Intensity Mapping

- detection of HI averaged from many galaxies
- cross-correlation with optical galaxies
- (in eg DEEP2, Chang et al)





Other:

* beyond lambda CDM:
  WDM, exotic cosmologies?
* Radio continuum as a noise source
* OH, detailed galaxy sims

Exotic Cosmologies

Tests of GR on galaxy scales as in Jain et al

1. stellar disk displaced from gas/dust disk
2. warps
3. asymmetry
4. gas rotation enhanced with respect to stars

Tests on larger scales eg lensing potential vs velocity potential


Pulsar Timing: 8khr
Test GR :
In blackhole-pulsar binary
Gravi. Waves using pulsar array?
PI Balies
LADUMA: 5khr
Deep HI single pointing
~1-4sq.deg to z~1,
"vuvuzela" survey volume
PI Baker, Blyth, Holwerda
MALS : 4khr
Absorption Line Survey
Pointed at 2000 brightest radio continuum sources
HI & OH absorption stats
Fundamental constants?
PI Gupta & Srianand
MHONGOOSE: 6khr
HI in 30 nearby Galaxies
Dark matter studies, cold accretion, cosmic web
PI de Blok
FORNAX: 2.5khr
HI in Fornax cluster
PI Serra
MESMER: 6.5 khr
Z>7 CO survey
1. Point at clusters
2. Point at quasars
3. Blank fiels
PI: Heywood
MIGHTEE: 2khr
Continuum survey
35sq.deg to 1μJy
0.1sq.deg to 0.1μJy
Faint radio AGN, starforming galaxies & relics in clsuters
PI Jarvis & vanderHeyden
MeerGAL (3.3khr)
Galactic plane survey
8-14 GHz
HII regions, masers, OB star mass loss, dust
PI Thompson & Goedhart
ThunderKAT: 3khr
Slow transients
PI Fender & Woudt
TRAPUM: 3khr
Fast transients
PI Stappers & Kramer
MeerKAT:
South African precursor to Square Kilometer Array:
64 dishes (13.5m diam, offset gregorian)
Phase I: 0.7-1.7GHz & 8-14GHz, 8km baseines
Later: 8-14GHz and 20-60km baselines
~5 years (44 kilohour) given to surveys listed here
Science by 2016, currently 7 dishes (KAT7)